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Co-existence of stochastic and chaotic behaviour in the copper price time series

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ABSTRACT

The possible scarcity of copper (and the likely resulting pressure on prices) is an issue of concern, especially in the light of its importance for the ever growing networking industry. Also for that reason, copper is the nonferrous metal most traded in the markets. Therefore, assessing the nature of its price fluctuations is an important task. Several papers have been devoted to analysing the characteristics of the time series of copper prices, especially for the purpose of predicting its future behaviour. The field of approaches can be divided roughly equally between those adopting a stochastic model and those opting for a deterministic nonlinear (chaotic) model. Nevertheless, while papers employing the stochastic paradigm have completely ignored the presence of chaotic features, at the same time papers recognizing the chaotic paradigm have neglected the presence of noise.The purpose of this paper is to investigate copper price behaviour in the CMX, considering a very long time series and adopting estimation methods that provide the coexistence of stochastic and chaotic features. We find that: a) the presence of noise is very significant (amounting to more than a quarter of the average signal value), as well as the presence of chaotic features; b) intermittency is present, which may be indicative of a bubble-related value that emerged without any fundamental cause.

1. Introduction

The possible scarcity of copper (and the likely resulting pressure on prices) is an issue of concern (Gordon et al., 2006; Tilton and Lagos, 2007), especially in the light of its importance for the ever growing networking industry. Also for that reason, copper is the nonferrous metal most traded in the markets (NYMEX states that copper is the third most widely used metal). Assessing the nature of its price fluctuations is therefore an important task.

Several papers have been devoted to analysing the characteristics of the time series of copper prices (typically the gains/losses deriving from price changes), especially for the purpose of predicting its future behaviour.

The field of approaches can be divided roughly equally between those adopting a stochastic model and those opting for a deterministic nonlinear (chaotic) model, with some exceptions. Examples of the first approach are found in Wets and Rios (2015), Geman and Shih (2009), Khalifa et al. (2011), Chen (2010). Two different processes, for the short term and the long term respectively, are proposed in Wets and Rios (2015). A constant elasticity of variance (CEV) model is instead proposed in Geman and Shih (2009), where the method of moments is employed to estimate the parameters. In Khalifa et al. (2011) the volatility is estimated using several dataset extracted at different time intervals. The estimation of volatility is likewise the goal of Chen (2010).

An econometric model, employing a large number of regressors (both financial and fundamental), has instead been proposed in Buncic and Moretto (2015), where a linear model with time-varying coefficients is adopted. A spectral approach, employing band-pass filtering to extract periodic components, has been adopted in Cuddington and Jerrett (2008) to assess the existence, frequency, and amplitude of the so called super cycles.

On the other hand, some papers have found clear signs of chaotic behaviour (Decoster et al., 1992; Carrasco et al., 2015). In particular, Carrasco et al. examined a very long time series, from 1976 to 2013, using a variety of methods: recurrence plots, Fourier spectrum analysis, Lyapunov exponent, Hurst exponent (Carrasco et al., 2015). Through the first two methods they obtained qualitative results suggesting the presence of chaos, but also estimated a Lyapunov exponent roughly around -3.2 by using the Rosenstein method (Rosenstein et al., 1993). Through the use of the R/S statistics, they also found a Hurst exponent in the [0.62,0.64] range, exhibiting a fractal characteristic (though the

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use of the R/S statistics is not a reliable method to detect long-range dependence, and wavelet methods, e.g., have shown to be preferable Beran, 1994; De Giovanni and Naldi, 2004). Among the more cautious analyses of chaotic behaviours, Panas found evidence of a self-similar (i.e. fractal) behaviour, but no clear indication of chaos (Panas, 2001), while Yang and Brorsen, though not rejecting the chaotic hypothesis, found the GARCH(1,1) process with residuals following a Student's t-distribution to come closest to fitting the data (Yang and Brorsen, 1994).

However, while papers employing the stochastic paradigm have completely ignored the presence of chaotic features, at the same time papers recognizing the chaotic paradigm have neglected the presence of noise.

In this paper, we wish to refine the analysis of chaotic behaviour in copper prices by examining a very long time series (spanning 28 years) and incorporating the presence of noise in the estimation of chaotic features. In particular, we apply in this context some of the techniques that we have used in Mastroeni et al. (2018).

After describing the main features of our dataset in Section 2, we provide the following contributions:

- we identify the deterministic nonlinear framework for the analysis of copper prices (Section 3);
- we show that the time series exhibits chaotic behaviour though in the presence of noise, since its Kolmogorov-Sinai entropy, corrected for the presence of noise, has a stable non-zero value (Section 4.1);
- we observe an intermittency behaviour, where periods of laminar phases are interleaved with periods of chaotic behaviour (Section 4.2);
- we estimate the level of noise, which amounts to more than a quarter of the average signal value (Section 4.3).

2. The dataset

In order to assess the presence of chaotic features in copper prices, we consider a real dataset. In this section, we describe that dataset and compare it to the datasets employed in the past literature for the same purpose.

The dataset employed in our analysis is the time series of daily Generic 1st Futures Copper closing prices (HG1 ticker) as exchanged on the COMEX market (CMX) and retrieved from the Bloomberg website. The COMEX market is one of the four marketplaces managed by the CME group. The dataset spans nearly 30 years, from December 7th, 1989 till February 20th, 2017. The overall time series is shown in Fig. 1.

The plot reveals the most relevant periods and events in that market. In particular, we can observe the long period of low prices

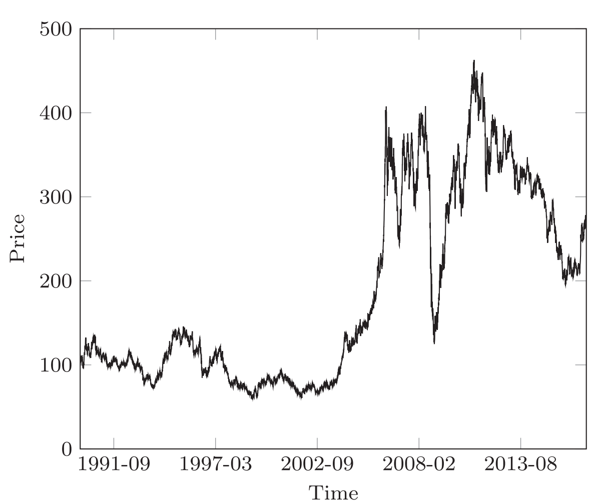

Fig. 1. Copper futures prices on the COMEX market.

Table 1
Datasets employed for copper prices analysis in the literature. Acronyms: LME denotes London Metal Exchange; NYMEX denotes New York Mercantile Exchange; USGS denotes US Geological Survey (an online digital database). The dataset in Yang and Brorsen (1994) was taken from the Dunn & Hargitt Commodity Data Bank.

Market	Period start	Period end	Sampling	Reference
NYMEX	Jan 1968	March 1989	Daily	Decoster et al. (1992)
Various	Jan 1979	Dec 1988	Bi-monthly	Yang and Brorsen (1994)
LME	Jan 1989	Dec 2000	Daily	Panas (2001)
LME	June 1996	June 2014	Monthly	Buncic and Moretto (2015)
LME	Jan 1980	Nov 2012	Monthly	Wets and Rios (2015)
LME	1850	2005	Annual	Cuddington and Jerrett (2008)
LME	Jan 1990	Dec 2007	Daily	Geman and Shih (2009)
NYMEX	Jan 1999	Dec 2008	1–15 min	Khalifa et al. (2011)
USGS	1900	2007	Annual	Chen (2010)

during the decade 1990–2000, marked by the USSR collapse in 1991 (the subsequent fall of internal demand and rise of its exports of copper, leading to a supply increase supply) and the financial crises in Southeast Asia in 1997–98 (the nominal price fell by more than 50% between 1995 and 1999). The period of low prices was followed by the strongest price increase since WW2 in the years 2003–2011, with a brief dip in 2008–09 (the start of the crisis in Western economies). Finally, a price decline is visible from 2011 to date, as a result of both investment in capacity (with the subsequent increase in potential supply), induced by the preceding high prices, and the slowdown in Chinese growth. In addition, low energy prices have helped reduce costs for mining and refining.

For comparison we report in Table 1 the main features of the datasets employed so far in the literature on copper price analysis. The majority was employed for classical time series analysis. A major advantage of our dataset is that we extend to 30 years the period of analysis, while the three datasets employed so far for chaos identification just extended over 21, 9, and 11 years respectively.

Looking at Fig. 1, we observe that the first half of the time series is mainly random (as the average is almost constant), while in the second half clear movements can be seen. Hence, having identified the peak value of the copper futures prices series, we have splitted the series in correspondence of the half of that peak (approximately at 06.02.2006). Thus we will conduct our analysis on the following three temporal ranges: 07.12.1989–03.02.2006, 06.02.2006–20.02.2017 and the full time range.

3. Phase space reconstruction

In order to analyse copper prices in a nonlinear framework, we need to reconstruct the phase space in which the time series of prices is embedded. In this section, we describe such embedding and estimate the relevant parameters.

As in purely deterministic systems, we consider a phase space, where a point describes the state of the system, so that the future state is a function of the present state. If the dimension of the phase space is m, and the state at time i is $\underline{S}_i$, we have $\underline{S}_{i+1} = F(\underline{S}_i)$, where the function F maps the present state into the future state.

In our case we just observe the time series of prices $\{x_1, x_2, \ldots, x_n\}$ (with $x_i \in \mathbb{R}_+$ since we are dealing with prices, which are strictly positive) and derive the time series of logarithmic returns $z_i = \ln\frac{x_i}{x_{i-1}}$, where now $z_i \in \mathbb{R}$. As shown in the seminal paper by Packard et al. (1980), the phase space can be reconstructed from experimental data, namely the time series of observations, which represents a one-dimension view of the system's trajectory in the m-dimensional phace space. In order to go back to the phase space, we need a method to map the time series of logarithmic returns onto the state. Here we adopt the